UNIT # 8
THERMAL PROPERTIES OF MATTER

Q1. Define the terms heat and temperature.

Ans: Heat:

Heat is the energy that is transferred from one body to the other in thermal contact with each other as a result of the difference of temperature between them.

Temperature:

Temperature of a body is the degree of hotness or coldness of the body.

Q2. Define the terms thermal conduct and thermal equilibrium.

Ans: Thermal conduct:

In heat transfer and thermodynamics, a thermodynamic system is said to be in **thermal contact** with another system if it can exchange energy with it through the process of heat.

Thermal equilibrium:

Thermal equilibrium - When two objects A and B are in thermal contact and there is no net transfer of thermal energy from A to B or from B to A, they are said to be in thermal equilibrium.

Q3. Define the terms energy in transit and internal energy.

Ans: Energy in transit:

The form of energy that is transferred from a hot body to a cold body is called heat. Thus Heat is therefore, called as the **energy in transit**.

Once heat enters a body, it becomes its **internal energy** and no longer exists as heat energy.

Internal energy:

The sum of kinetic energy and potential energy associated with the atoms, molecules and particles of a body is called its internal energy.

Internal energy of a body depends on many factors such as the mass of the body, kinetic and potential energies of molecules etc.

Q4. Differentiate between temperature and heat?

Ans: Heat:

Heat (symbol: *Q*) is energy. It is the total amount of energy (both kinetic and potential) possessed by the molecules in a piece of matter. Heat is measured in Joules.

Temperature:

Temperature (symbol: *T*) is not energy. It relates to the average (kinetic) energy of microscopic motions of a single particle in the system per degree of freedom. It is measured in Kelvin (K), Celsius (^{o}C) or Fahrenheit (^{o}F).

Explanation:

Heat is the total energy of molecular motion in a substance while temperature is a measure of the average energy of molecular motion in a

substance. Heat energy depends on the speed of the particles, the number of particles (the size or mass), and the type of particles in an object. Temperature does not depend on the size or type of object. For example, the temperature of a small cup of water might be the same as the temperature of a large tub of water, but the tub of water has more heat because it has more water and thus more total thermal energy.

Note: Temperature is not energy, but a measure of it. Heat is energy.

DO YOU KNOW?

The **crocus flower** is a natural thermometer. It opens when the temperature is precisely 23°C and closes when the temperature drops.

Mini Exercise

1. Which of the following substances have greater average kinetic energy of its molecules at 10 °C?

(a) steel (b) copper (c) water (d) mercury

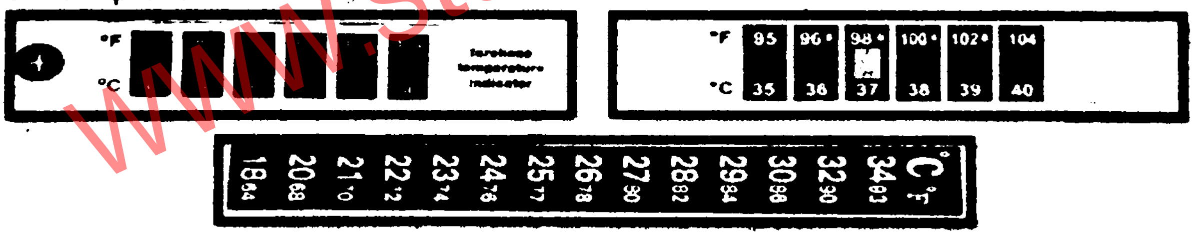
Ans: At 10 °C water molecules have greater kinetic energy. Due to lesser intermolecular forces as compared to steel, copper and mercury.

2. Every thermometer makes use of some property of a material that varies with temperature. Name the property used in:

(a) strip thermometers (b) mercury thermometers

Ans: (a) strip thermometers:

Liquid-crystal thermometers use liquid crystals that change color in response to temperature changes. Mixtures of liquid crystals are enclosed in separate partitions. Numbers on the partitions indicate temperatures according to the amount of heat present.



(b) mercury thermometers:

Mercury thermometers are based on the fact that materials (in this case, the liquid mercury) expand when heated.

Mercury has uniform thermal expansion, easily visible, has low freezing point, has high boiling point and less specific heat.

Note: Due to these properties mercury is used in mercury thermometer. Since it is opaque, it is easy to see the capillary.

Q5. What is a thermometer? Why mercury is preferred as a thermometric substance?

Ans: See Q # 8.6 from Exercise.

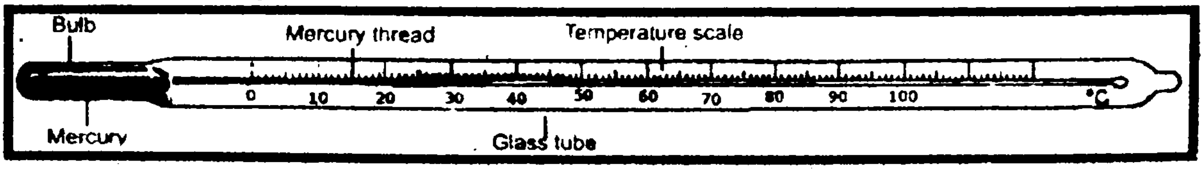
Q6. Describe the feature of liquid-in-glass thermometer

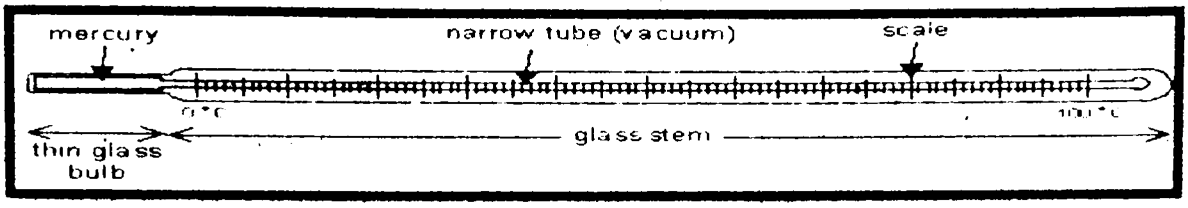
OR

Describe the feature of mercury-in-glass thermometer

Ans: Liquid-in-glass thermometer:

A liquid-in-glass thermometer has a bulb with a long capillary tube of uniform and fine bore. A suitable liquid is filled in the bulb. When the bulb contacts a hot object, the liquid in it expands and rises in the tube. The glass stem of a thermometer is thick and acts as a cylindrical lens. This makes it easy to see the liquid level in the glass tube.





A mercury-in-glass thermometer

Mercury freezes at $-39^{\circ}C$ and boils at $357^{\circ}C$.

Uses:

Thus mercury is one of the most suitable thermometric material. Mercury-in-glass thermometers are widely used in laboratories, clinics and houses to measure temperatures in the range from $-10^{\circ}C$ to $150^{\circ}C$.

Q7. What do you mean by lower and upper fixed points in thermometer?

Ans: Lower and upper fixed points:

A thermometer has a scale on its stem. This scale has two fixed points. The lower fixed point is marked to show the position of liquid in the thermometer when it is placed in ice.

Similarly, upper fixed point is marked to show the position of liquid in the thermometer when it is placed in steam at standard pressure above boiling water.

Q8. Highlight the different scale of temperature from one scale to another (Fahrenheit, Celsius and Kelvin scales)

Ans: Scales of temperature:

A scale is marked on the thermometer. The temperature of the body in contact with the thermometer can be read on. that scale. Three scales of temperature are in common use. These are:

(i) Celsius scale or centigrade scale

(ii) Fahrenheit scale

(iii) Kelvin scale

Celsius scale:

On Celsius scale, the interval between lower and upper fixed points is divided into 100 equal parts. The lower fixed point is marked as $0^{\circ}C$ and the upper fixed point is marked as $100^{\circ}C$.

Fahrenheit scale:

On Fahrenheit scale, the interval between lower and upper fixed points is divided into 180 equal parts. Its lower fixed point is marked as $32^{\circ}F$ and upper fixed point is marked as $212^{\circ}F$.

Kelvin scale:

In SI units, the unit of temperature is Kelvin (K) and its scale is called Kelvin scale of temperature. The interval between the lower and upper fixed points is divided into 100 equal parts. Thus, a change in 1°C is equal to a change of 1K. The lower fixed point on this scale corresponds to 273 K and the upper fixed point is referred as 373 K. The zero on this scale is called the absolute zero and is equal to −273°C.

	°C	°F	K
Boiling point of water	100	212	373
Freezing point of water	0	32	273

DO YOU KNOW?

Sun's core	15000000 °C
Sun's surface	6000 °C
Electric lamp	2500 °C
Gas lamp	1580°C
Boiling water	100°C
Human body	37 °C
Freezing water	0 °C
Ice in freezer	-18 °C
Liquid oxygen	-180 °C

Q9. How can you convert the temperature from one scale to another (Fahrenheit, Celsius and Kelvin scales)

Ans: Conversion of temperature from one scale into other temperature scale:

From Celsius to Kelvin Scale:

The temperature T on Kelvin scale can be obtained by adding 273 in the temperature C on Celsius scale. Thus

$$T(K) = 273 + C \quad \ldots\ldots\ldots\ldots \text{(i)}$$

From Kelvin to Celsius scale:

The temperature on Celsius scale can be found by subtracting 273 from the temperature in Kelvin Scale. Thus

$$C = T(K) - 273 \quad \text{(ii)}$$

From Celsius to Fahrenheit scale:

Since 100 divisions on Celsius scale are equal to 180 divisions on Fahrenheit scale. Therefore, each division on Celsius scale is equal to 1.8 divisions on Fahrenheit scale. Moreover, 0°C corresponds to 32°F.

$$\therefore \quad F = 1.8C + 32 \quad \ldots\ldots\ldots\ldots \text{(iii)}$$

Here F is the temperature on Fahrenheit scale and C is the temperature on Celsius scale.

DO YOU KNOW?

A clinical thermometer is used to measure, the temperature of human body. It has a narrow range from 35 °C to 42 °C. It has a constriction that prevents the mercury to return. Thus, its reading does not change until reset.

USEFUL INFORMATION

Specific heat of some common substances

Substance	Specific heat ($Jkg^{-1}K^{-1}$)
Alcohol	2500.0
Aluminum	903.0
Bricks	900.0
Carbon	121.0
Clay	920.0
Copper	387.0
Ether	2010.0
Glass	840.0
Gold	128.0
Granite	790.0
Ice	2100.0
Iron	470.0
Lead	128.0
Mercury	138.6
Sand	835.0
Silver	235.0
Soil (dry)	810.0
Steam	2016.0
Tungsten	134.8
Turpentine	1760.3
Water	4200.0
Zinc	385.0

Q10. Define specific heat. How would you find the specific heat of a solid?

Ans: See Q # 8.8 from Exercise.

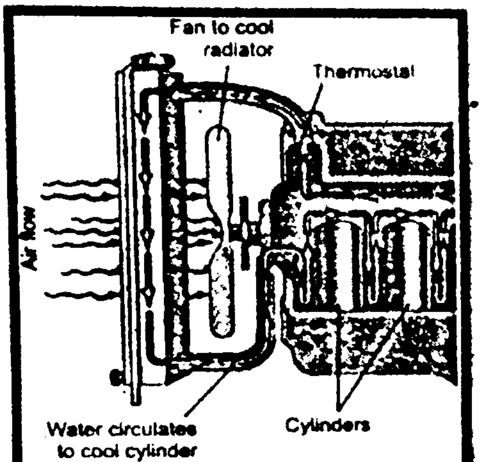
Q11. Describe the Importance of large specific heat capacity of water

Ans: Importance of large specific heat capacity of water:

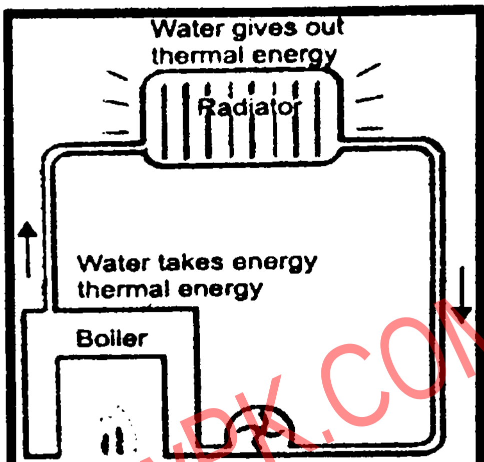
Specific heat of water is 4200 $Jkg^{-1}K^{-1}$ and that of dry soil is about 810 $Jkg^{-1}K^{-1}$. As a result the temperature of soil would increase five times more than the same mass of water by the same amount of heat. Thus, the temperature of land rises and falls more rapidly than that of the sea. Hence, the temperature variations from summer to winter are much smaller at places near the sea than land far away from the sea.

Storing and carrying thermal energy:

Water has a large specific heat capacity. For this reason, it is very useful in storing and carrying thermal energy due to its high specific heat capacity. The cooling system of automobiles uses water to carry away unwanted thermal energy. In an automobile, large amount of heat is produced by its engine due to which its temperature goes on increasing. The engine would cease unless it is not cooled down. Water circulating around the engine by arrows in maintains its temperature. Water absorbs unwanted thermal energy of the engine and dissipates heat through its radiator.



A Cooling system in automobile



Central heating system

Central heating systems:

In central heating systems hot water is used to carry thermal energy through pipes from boiler to radiators. These radiators are fixed inside the house at suitable places.

DO YOU KNOW?

The presence of large water reservoirs such as lakes and seas keep the climates of nearby land moderate due to the large heat capacity of these reservoirs.

Q12. Define heat capacity. How would you find the heat capacity of a solid?

Ans: Heat capacity:

Heat capacity of a body is the quantity of thermal energy absorbed by it for one kelvin (1 K) increase in its temperature.

If the temperature of a body increases through ΔT on adding ΔQ amount of heat, then its heat capacity will be $\frac{\Delta Q}{\Delta T}$. Putting the value of ΔQ, we get

$$\text{Heat capacity} = \frac{\Delta Q}{\Delta T} = \frac{mc\Delta T}{\Delta T}$$

$$\text{Heat capacity} = mc \quad \ldots\ldots\ldots\ldots\ldots \quad \text{(i)}$$

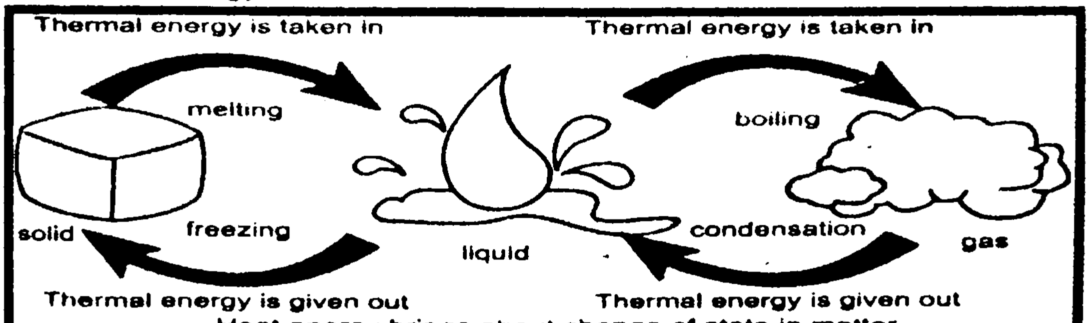
Equation (i) shows that heat capacity of a body is equal to the product of its mass of the body and its specific heat capacity.

For example, heat capacity of 5 kg of water is (5 kg × 4200 $Jkg^{-1}K^{-1}$) 21000 JK^{-1}. That is; 5 kg of water needs 21000 joules of heat for every 1 K rise in its temperature. Thus, larger is the quantity of a substance, larger will be its heat capacity.

Q13. Describe activity to determine the change of state of ice into water and steam by sketching graph.

Ans: Change of state:

Matter can be changed from one state to another. For such a change to occur, thermal energy is added to or removed from a substance.



Heat energy brings about change of state in matter

ACTIVITY:

Take a beaker and place it over a stand. Put small pieces of ice in the beaker and suspend a thermometer in the beaker to measure the temperature of ice.

Now place a burner under the beaker. The ice will start melting. The temperature of the mixture containing ice and water will not increase above 0°C until all the ice melts and we get water at 0°C. If this water at 0°C is further heated, its temperature will begin to increase above 0°C as shown by the graph in figure. 8.9.

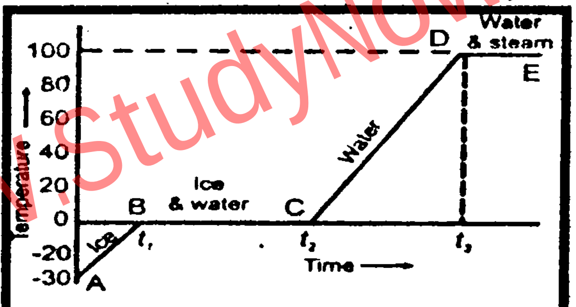


Figure: A graph of temperature and time showing change of state of ice into water and steam.

Part AB: On this portion of the curve, the temperature of ice increases from -30°C to 0°C.

Part BC: When the temperature of ice reaches 0°C, the ice water mixture remains at this temperature until all the ice melts.

Part CD: The temperature of the substance gradually increases from 0°C to 100°C. The amount of energy so added is used up in increasing the temperature of water.

Part DE: At 100°C water begins to boil and changes into steam. The temperature remains 100°C untill all the water changes into steam.

Q14. Define fusion point and freezing point?

Ans: Fusion point or melting point:

When a substance is changed from solid to liquid state by adding heat, the process is called melting or fusion.

The temperature at which a solid starts melting is called its fusion point or melting point.

Freezing point:

The temperature at which a substance changes from liquid to solid state is called its freezing point. However, the freezing point of a substance is the same as its melting point.

Q15. Define and explain latent heat of fusion.

Ans: See Q # 8.9 from Exercise.

Q16. Find the latent heat of fusion of ice with the help of experiment.

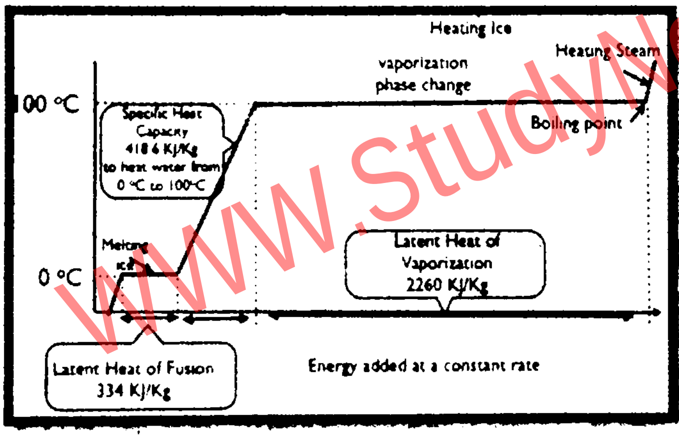
OR

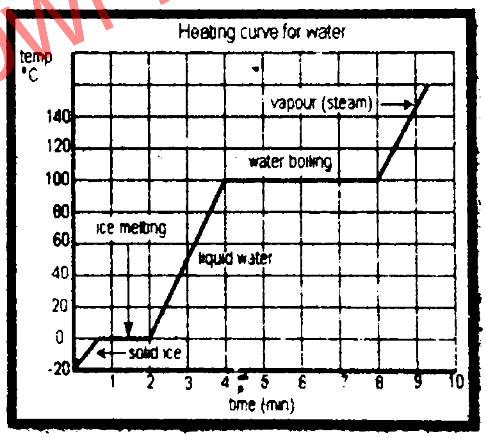
Describe experiments to determine heat of fusion and latent heat of fusion of ice by sketching temperature-time graph on heating ice.

Ans: Experiment:

Take a beaker and place it over a stand. Put small pieces of ice in the beaker and suspend a thermometer in the beaker to measure the temperature. Place a burner under the beaker. The ice will start melting. The temperature of the mixture containing ice and water will not increase above $0^\circ C$ until all the ice melts. Note the time which the ice takes to melt completely into water at $0^\circ C$.

Continue heating the water at $0^\circ C$ in the beaker. Its temperature will begin to increase. Note the time which the water in the beaker takes to reach its boiling point at $100^\circ C$ from $0^\circ C$.





Draw a temperature-time graph such as shown in figure 8.11. Calculate the latent heat of fusion of ice from the data as follows:

Let mass of ice = m

Finding the time from the graph:

Time taken by ice to melt completely at $0^\circ C$ $= t_f = t_2 - t_1 =$ 3.6 min.

Time taken by water to heat from $0^\circ C$ to $100^\circ C$ $= t_o = t_3 - t_2 =$ 4.6 min.

Specific heat of water $c = 4200\ Jkg^{-1}K^{-1}$

Increase in the temperature of water $= \Delta T = 100^\circ C = 100\ K$

Heat required by water from $0^\circ C$ to $100^\circ C$ $= \Delta Q = m c \Delta T$

$$= m \times 4200\ Jkg^{-1}K^{-1} \times 100K$$

$$= m \times 420\,000\ Jkg^{-1}$$

$$= m \times 4.2 \times 10^5\ Jkg^{-1}$$

Heat ΔQ is supplied to water in time t_o to raise its temperature from $0°C$ to $100°C$. Hence, the rate of absorbing heat by water in the beaker is given by

Rate of absorbing heat $= \frac{\Delta Q}{t_o}$

$\therefore$ Heat absorbed in time t_f $= \Delta Q = \frac{\Delta Q \times t_f}{t_o} = \Delta Q \times \frac{t_f}{t_o}$

Since $\Delta Q_f = m \times H_f$ (from eq. 8.7)

Putting the values, we get

$$m \times H_f = m \times 4.2 \times 10^5\ Jkg^{-1} \times \frac{t_f}{t_o}$$

or

$$H_f = 4.2 \times 10^5\ Jkg^{-1} \times \frac{t_f}{t_o}$$

The values of t_f and t_o can be found from the graph. Put the values in the above equation to get

$$H_f = 4.2 \times 10^5\ Jkg^{-1} \times \frac{3.6\ min}{4.6\ min}$$

$$= 3.29 \times 10^5\ Jkg^{-1}$$

The latent heat of fusion of ice found by the above experiment is $3.29 \times 10^5\ Jkg^{-1}$ while its actual value is $3.36 \times 10^5\ Jkg^{-1}$.

Q17. Define latent heat of vaporization.

Ans: See Q # 8.10 from Exercise.

Q18. List The value of melting point, boiling point, latent heat of fusion and vaporization of some of the substances?

Ans: Melting point, boiling point, latent heat of fusion and latent heat of vaporization of some common substances.

Substance	Melting point (°C)	Boiling point (°C)	Heat of fusion ($kJkg^{-1}$)	Heat of vaporization ($kJkg^{-1}$)
Aluminum	660	2450	39.7	10500
Copper	1083	2595	205.0	4810
Gold	1063	2660	64.0	1580
Helium	-270	-269	5.2	21
Lead	327	1750	23.0	858
Mercury	-39	357	11.7	270
Nitrogen	-210	-196	25.5	200
Oxygen	-219	-183	13.8	210
Water	0	100	336.0	2260

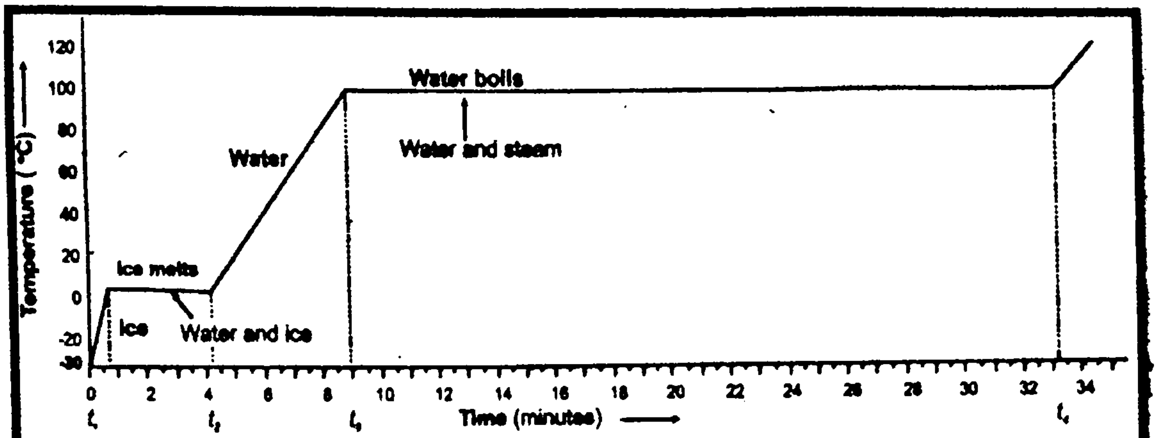
Q19. Find the latent heat of vaporization of water with the help of experiment.

OR

Describe experiment to determine heat of vaporization and heat of vaporization of water by sketching temperature-time graph.

Ans: Experiment:

At the end of experiment 8.1, the beaker contains boiling water. Continue heating water till all the water changes into steam. Note the time which the water in the beaker takes to change completely into steam at its boiling point $100°C$



Temperature-time graph as ice changes into water and water into steam on heating

Extend the temperature-time graph such as shown in figure. Calculate the latent heat of fusion of ice from the data as follows:

Let Mass of ice = m

Time t_0 taken to heat water from $0°C$ to $100°C$ (melt) $= t_o = t_3 - t_2 = 4.6$ min.

Time taken by water at $100°C$ to change it into steam $= t_4 = t_4 - t_3 = 24.4$ min.

Specific heat of water c $= 4200\ Jkg^{-1}K^{-1}$

Increase in the temperature of water $= \Delta T = 100°C = 100\ K$

Heat required to heat water from $0°C$ to $100°C$ $= \Delta Q = m c \Delta T$

$$= m \times 4200\ Jkg^{-1}K^{-1} \times 100\ K$$
$$= m \times 420\ 000\ Jkg^{-1}$$
$$= m \times 4.2 \times 10^5\ Jkg^{-1}$$

As burner supplies heat ΔQ to water in time t_o to raise its temperature from $0°C$ to $100°C$. Hence, the rate at which heat is absorbed by the beaker is given by

Rate of absorbing heat $= \dfrac{\Delta Q}{t_o}$

$\therefore$ Heat absorbed in time t_v $= \Delta Q_v = \dfrac{\Delta Q \times t_v}{t_o}$

$$= \frac{\Delta Q \times t_v}{t_o}$$

Since $\Delta Q_v = m \times H_v$ (from eq.8.8)

Putting the values, we get

$$m \times H_v = m \times 4.2 \times 10^5\ Jkg^{-1} \times \frac{t_v}{t_o}$$

or $$H_v = 4.2 \times 10^5\ Jkg^{-1} \times \frac{t_v}{t_o}$$

Putting the values of t_v and t_o from the graph, we get

$$H_v = 4.2 \times 10^5\ Jkg^{-1} \times \frac{24.4\ min}{4.6\ min}$$
$$= 2.23 \times 10^6\ Jkg^{-1}$$

The latent heat of vaporization of water found by the above experiment is $2.23 \times 10^6\ Jkg^{-1}$ while its actual value is $2.23 \times 10^6\ Jkg^{-1}$.

Q20 What is meant by evaporation? On what factors the evaporation of liquid depends? Explain how cooling is produced by evaporation.

Ans: See Q # 8.11 from Exercise.

Mini Exercise

1. How specific heat differs from heat capacity?

Ans:

Specific Heat	Heat Capacity
Specific heat of a substance is the amount of heat required to raise the temperature of 1kg mass of that substance through 1K.	Heat capacity of a body is the quantity of thermal energy absorbed by it for one kelvin (1K) increase in its temperature.
Specific heat can be found out by the relation. $c = \frac{\Delta Q}{m\Delta T}$	Heat capacity can be found out by the relation. Heat capacity = mc
SI unit of specific heat is $Jkg^{-1}K^{-1}$.	Unit of heat capacity is JK^{-1}.

2. Give two uses of cooling effect by evaporation.

Ans: Uses of cooling effect by evaporation:

i. During hot summers, the water is usually kept in the earthern pot to keep it cool. Water is cooled in the pot since the surface of the pot contains large pores and water seeps via these pores to outside of pot. This water evaporates and takes the latent heat for vaporisation hence retaining the water inside pot to be cooled.

ii. Especially in villages, people often sprinkle water on the ground in front of their homes during hot summers.

iii. Water vaporisation from leaves of trees also cools the surroundings.

iv. A desert cooler cools better on a hot and dry day.

v. It is a common observation that we are able to sip hot tea (or milk) faster from a saucer than from a cup.

vi. Wearing cotton clothes in summer days to keep the body cool and comfortable.

vii. Put a little of spirit on your hand and wave around, the spirit evaporates rapidly and our hands feels cooler.

3. How evaporation differs from vaporization?

Ans: Difference between Vaporization and Evaporation:

Vaporization:

Vaporization is a transitional phase of an element or compound from a solid phase or liquid phase to a gas phase. It changes matter from one state or phase into another without changing its chemical composition.

Vaporization has three types:

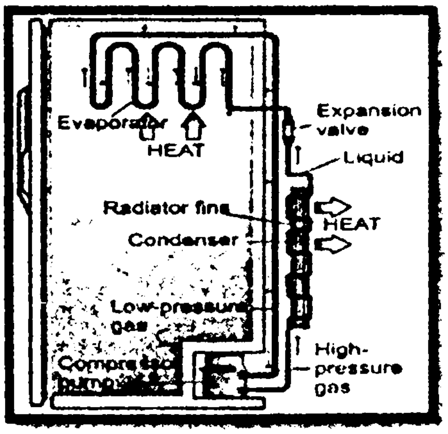
i. Boiling **ii.** Evaporation **iii.** sublimation

Evaporation:

Evaporation, wherein the transition from liquid phase to gas phase takes place below the boiling temperature at a given pressure, and it occurs on the surface.

COOLING IN REFRIGERATORS

Cooling is produced in refrigerators by evaporation of a liquified gas. This produces cooling effect. Freon, a CFC, was used as a refrigerant gas. But its use has been forbidden when it was known that CFC is the cause of ozone depletion in the upper atmosphere which results increase in amount of UV rays from the Sun. The rays are harmful to all living matter. Freon gas is now replaced by Ammonia and other substances which are not harmful to the environment.



Q21. Define thermal expansion.

Ans: Thermal expansion:

Thermal expansion is the tendency of matter to change in volume in response to a change in temperature.

On heating, the amplitude of vibration of the atoms or molecules of an object increases. They push one another farther away as the amplitude of vibration increases. Thermal expansion results an increase in length, breadth and thickness of a substance.

Q22. Derive the relation for linear thermal expansion in solids.

OR

Show that $L = L_o(1 + \alpha\,\Delta T)$?

Ans: Linear thermal expansion in solids:

Consider a metal rod of length L_o at certain temperature T_o. Let its length on heating to a temperature *T* becomes *L* Thus

Increase in length of the rod $= \Delta L = L - L_o$

Increase in temperature $= \Delta T = T - T_o$

It is found that change in length ΔL of a solid is directly proportional to its original length L_o, and the change in temperature ΔT. That is;

$$\Delta L \propto L_o\,\Delta T$$

or
$$\Delta L = \alpha\, L_o\,\Delta T \quad \text{.........} \quad \text{(i)}$$

or
$$L - L_o = \alpha\, L_o\,\Delta T$$

or
$$L = L_o + \alpha\, L_o\,\Delta T$$

or
$$L = L_o(1 + \alpha\,\Delta T) \quad \text{.........} \quad \text{(ii)}$$

Where α is called the coefficient of linear thermal expansion of the substance.

From equation (i), we get

$$\alpha = \frac{\Delta L}{L_o\,\Delta T} \qquad \text{(iii)}$$

Coefficient of linear expansion α:

We can define the coefficient of linear expansion α of a substance as the fractional increase in its length per kelvin rise in temperature.

Q23. Gives coefficient of linear thermal expansion of some common solids.

Ans: Table gives coefficient of linear thermal expansion of some common solids.

Coefficient of linear thermal expansion (α) of some common solids	
Substance	$\alpha\ (K^{-1})$
Aluminum	2.4×10^{-5}
Brass	1.9×10^{-5}
Copper	1.7×10^{-5}
Steel	1.2×10^{-5}
Silver	1.93×10^{-5}
Gold	1.3×10^{-5}
Platinum	8.6×10^{-5}
Tungsten	0.4×10^{-5}
Glass (pyrex)	0.4×10^{-5}
Glass(ordinary)	0.9×10^{-5}
Concrete	1.2×10^{-5}

Q24. Explain the volumetric thermal expansion.

OR

Derive the relation for volume thermal expansion in solids.

OR

Show that $V = V_0(1 + \beta\ \Delta T)$?

Ans: See Q # 8.7 from Exercise.

Q25. Give the values of β for different substances?

Ans: Values of β for different substances are given in Table

Coefficient of volume expansion of various substances.	
Substance	$\beta(K^{-1})$
Aluminum	7.2×10^{-5}
Brass	6.0×10^{-5}
Copper	5.1×10^{-5}
Steel	3.6×10^{-5}
Platinum	27.0×10^{-5}
Glass(ordinary)	2.7×10^{-5}
Glass(pyrex)	1.2×10^{-5}
Glycerine	53×10^{-5}
Mercury	18×10^{-5}
Water	21×10^{-5}
Air	3.67×10^{-3}
Carbon dioxide	3.72×10^{-3}
Hydrogen	3.66×10^{-3}

Q26. Why gaps are left in railway tracks?

Ans: Gapes are left in railway tracks to compensates thermal expansion during hot season. Railway tracks buckled on a hot summer day due to expansion if gaps are not left between sections.

Q27. Why gaps are left in bridges with rollers?

Ans: Bridges made of steel girders also expand during the day and contract during night. They will bend if their ends are fixed. To allow thermal expansion, one end is fixed while the other end of the girder rests on rollers in the gap left for expansion.

Q28. Why overhead transmission lines (wires on electric poles) are also given a certain amount of sag?

Ans: Overhead transmission lines are also given a certain amount of sag so that they can contract in winter without snapping.

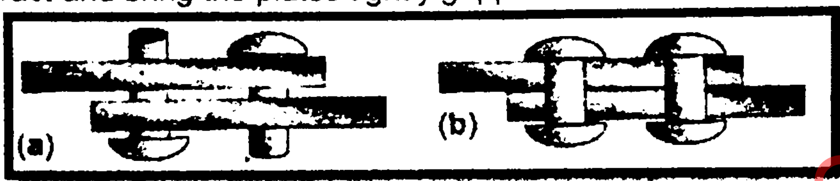
Q29. List the application of thermal expansion?

Ans: Application of thermal expansion:

i. In thermometers, thermal expansion is used in temperature measurements.

ii. To open the cap of a bottle that is tight enough, immerse it in hot water for a minute or so. Metal cap expands and becomes loose. It would now be easy to turn it to open.

iii. To join steel plates tightly together, red hot rivets are forced through holes in the plates. The end of hot rivet is then hammered. On cooling, the rivets contract and bring the plates tightly gripped.

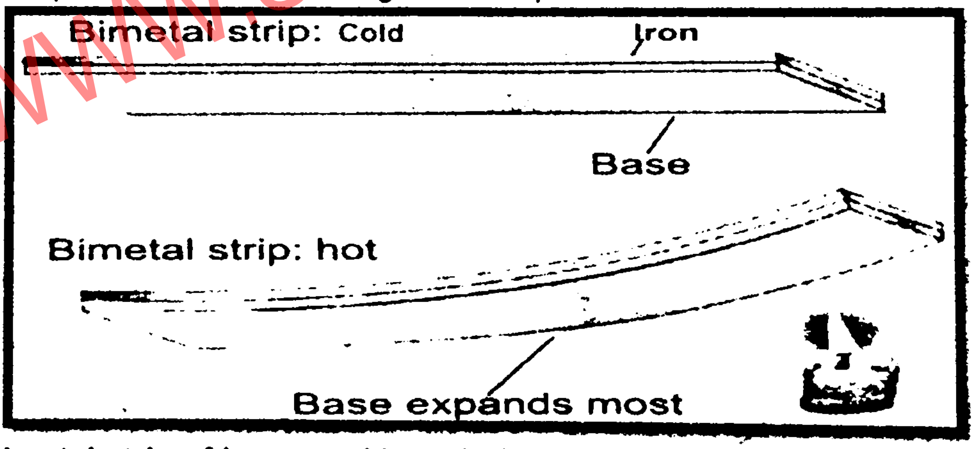


iv. Iron rims are fixed on wooden wheels of carts. Iron rims are heated. Thermal expansion allows them to slip over the wooden wheel. Water is poured on it to cool. The rim contracts and becomes tight over the wheel.

Q30. Explain that the bimetallic strip used in thermostat is based on different rate of expansion of different metals on heating.

Ans: Bimetal strip:

A bimetal strip consists of two thin strips of different metals such as brass and iron joined together. On heating the strip, brass expands more than iron. This unequal expansion causes bending of the strip.



(a) A bimetal strip of brass and iron (b) Bending of brass-iron bimetal strip on heating due to the difference in their thermal expansion.

Uses of bimetal strips:

(i) Bimetal thermometers are used to measure temperatures especially in furnaces and ovens.

(ii) Bimetal strips are also used in thermostats.

(iii) Bimetal thermostat switch such is used to control the temperature of heater coil in an electric iron.

DO YOU KNOW?

Anomalous expansion of water:

Water on cooling below 4°C begins to expand until it reaches 0°C. On further cooling its volume increases suddenly as it changes into ice at 0°C. When ice is cooled below 0°C, it contracts i.e. its volume decreases like solids. This unusual expansion of water is called the **anomalous expansion of water.**

Q31. Why the coefficient of volume expansion of liquids is greater than solids?

Ans: The molecules of liquids are free to move in all directions within the liquid. On heating a liquid, the average amplitude of vibration of its molecules increases. The molecules push each other and need more space to occupy. This accounts for the expansion of the liquid when heated. The thermal expansion in liquids is greater than solids due to the weak forces between their molecules. Therefore, the coefficient of volume expansion of liquids is greater than solids.

Liquids have no definite shape of their own. A liquid always attains shape of the container in which it is poured. Therefore, when a liquid is heated, both liquid and the container undergo a change in their volume.

Q32. Explain thermal expansion of liquids

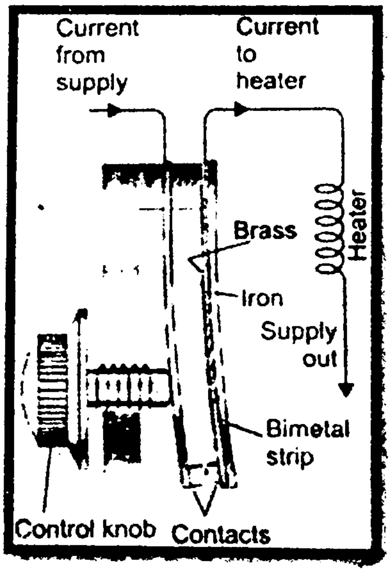
OR

Differentiate between real and apparent expansion of liquid?

Ans: Thermal expansion of liquids:

Thus, there are two types of thermal volume expansion for liquid.

- Apparent volume expansion
- Real volume expansion



ACTIVITY:

Take a long-necked flask. Fill it with some coloured liquid upto the mark A on its neck as shown in figure. Now start heating the flask from bottom. The liquid level first falls to B and then rises to C.

The heat first reaches the flask which expands and its volume increases. As a result liquid descends in the flask and its level falls to B. After sometime, the liquid begins to rise above B on getting hot. At certain temperature it reaches at C. The rise in level from A to C is due to the apparent expansion in the volume of the liquid. Actual expansion of the liquid is greater than that due to the expansion because of the expansion of the glass flask. Thus real expansion of the liquid is equal to the volume difference between A and C in addition to the volume expansion of the flask. Hence

Real expansion of the liquid = Apparent expansion of the flask = Expansion of the liquid

or $BC = AC + AB$ (i)

The expansion of the volume of a liquid taking into consideration the expansion of the container also, is called the real volume expansion of the liquid. The real rate of volume expansion β_r of a liquid is defined as the actual change in the unit volume of a liquid for 1K (or 1°C) rise in its temperature. The real rate of volume expansion β_r is always greater than the apparent rate of volume expansion β_a by an amount equal to the rate of volume expansion of the container β_g. Thus

$$\beta_r = \beta_a + \beta_g \quad \text{................ (ii)}$$

It should be noted that different liquids have different coefficients of volume expansion.

SUMMARY

1. **Temperature:** The temperature of a body is the degree of hotness or coldness of the body.
2. **Thermometers:** Thermometers are made to measure the temperature of a body or places.
3. **Position of mercury:** The lower fixed point is the mark that gives the position of mercury in the thermometer when it is placed in ice.
4. **Point of mercury:** The upper fixed point is the mark that shows the point of mercury in the thermometer when it is placed in steam from boiling water at standard pressure.
5. Inter-conversion between scales:
6. From Celsius To Kelvin Scale: $T(K) = 273 + C$
7. From Kelvin to Celsius Scale: $C = T(K)-273$
   From Celsius to Fahrenheit Scale: $F = 1.8\,C + 32$
8. **Heat:** Heat is a form of energy and this energy is called heat as long as it is in the process of transfer from one body to another body. When a body is heated, the kinetic energy of its molecules increases, the average distances between the molecules increase.
9. **Specific heat:** The specific heat of a substance is defined as the amount of heat required to raise the temperature of a unit mass of that substance through one degree centigrade (1°C) or one kelvin (1K).
10. **Latent heat of fusion:** The heat required by unit mass of a substance at its melting point to change it from solid state to liquid state is called the latent heat of fusion.
11. **Latent heat of vaporization:** The quantity of heat required by the unit mass of a liquid at a certain constant temperature to change its state completely from liquid into gas is called the latent heat of vaporization.
12. It has been observed that solids expand on heating and their expansion is nearly uniform over a wide range of temperature. Mathematically,

$$L = L_o(1 + \alpha\Delta T)$$

13. **Thermal coefficient of linear expansion α:** The thermal coefficient of linear expansion α of a substance is defined as the fractional increase in its length per kelvin rise in temperature.

14. **Volume or cubical expansion:** The volume of a solid changes with the change in temperature and is called as volume or cubical expansion.

$$V = V_o(1 + \beta\Delta T)$$

15. **Thermal coefficient of volume expansion β:** The thermal coefficient of volume expansion β is defined as the fractional change in its volume per kelvin change in temperature.

16. **Types of thermal volume expansion for liquid:** There are two types of thermal volume expansion for liquids as well as for gases. Apparent volume expansion and real volume expansion.

QUESTIONS

8.1 Encircle the correct answer from the given choices.

i. Water freezes at

A. 0 °F B. 32 °F
C. −273 K D. 0 K

ii. Normal human body temperature is

A. 15 °C B. 37 °C
C. 37 °F D. 98.6 °C

iii. Mercury is used as thermometric material because it has

A. uniform thermal expansion B. low freezing point
C. small heat capacity D. all the above properties

iv. Which of the following material has large specific heat?

A. copper B. ice
C. water D. mercury

v. Which of the following material has large value of temperature coefficient of linear expansion?

A. aluminum B. gold
C. brass D. steel

vi. What will be the value of β for a solid for which α has a value of $2 \times 10^{-5}K^{-1}$?

A. $2 \times 10^{-5}K^{-1}$ B. $6 \times 10^{-5}K^{-1}$
C. $8 \times 10^{-15}K^{-1}$ D. $8 \times 10^{-5}K^{-1}$

vii. A large water reservoir keeps the temperature of nearby land moderate due to

A. low temperature of water B. low specific heat of water
C. less absorption of heat D. large specific heat of water

viii. Which of the following affects evaporation?

A. temperature B. surface area of the liquid
C. wind D. all of the above

Answers

i. B	ii. B	iii. D	iv. C	v. A	vi. B	vii. D	viii. D

8.2 Why does heat flow from hot body to cold body?

Ans: Heat flows from warm to cold because the energy state is higher.

Heat flow moves energy from a higher temperature to a lower temperature. The bigger the difference in temperature between two objects, the faster heat flows between them. When temperatures are the same there is no change in energy due to heat flow. Heat flows from a hot body to a cold body until thermal equilibrium is reached.

Radiation and Conduction are the two methods of heat transfer. Convection is a special type of conduction.

8.3 Define the terms heat and temperature.

Ans: Heat:

Heat is the energy that is transferred from one body to the other in thermal contact with each other as a result of the difference of temperature between them.

Temperature:

Temperature of a body is the degree of hotness or coldness of the body.

8.4 What is meant by internal energy of a body?

Ans: Internal energy:

The sum of kinetic energy and potential energy associated with the atoms, molecules and particles of a body is called its internal energy.

Internal energy of a body depends on many factors such as the mass of the body, kinetic and potential energies of molecules etc.

$$\Delta U = Q - W$$

Where, ΔU= internal energy, Q =Heat and W = Work done.

8.5 How does heating affect the motion of molecules of a gas?

Ans: The larger the temperature of a gas the faster the molecules will move (temperature is proportional to the average kinetic energy of the particles) and the larger the force they will exert, and the higher the pressure (pressure is the force exerted by the particles divided by the area).

$$T \propto K.E \propto P$$

8.6 What is a thermometer? Why mercury is preferred as a thermometric substance?

Ans: Thermometer:

A device that is used to measure the temperature of a body is called thermometer.

Principle of thermometer:

Mercury thermometers are based on the fact that materials (in this case, the liquid mercury) expand when heated.

Basic properties of thermometric liquid:

A thermometric liquid should have the following properties:

- It should be visible.
- It should have uniform thermal expansion.
- It should have a low freezing point.
- It should have a high boiling point.
- It should not wet glass.
- It should be a good conductor of heat.
- It should have a small specific heat capacity.

Preference of mercury:

Mercury has uniform thermal expansion, easily visible, has low freezing point, has high boiling point and less specific heat.

Note: Due to these properties mercury is used in mercury thermometer. Since it is opaque, it is easy to see the capillary.

8.7 Explain the volumetric thermal expansion.

Ans: Volume thermal expansion:

The volume of a solid also changes with the change in temperature and is called volume thermal expansion or cubical thermal expansion.

Consider a solid of initial volume V_o at certain temperature T_o. On heating the solid to a temperature T, let its volume becomes V, then

Change in the volume of a solid $\Delta V = V - V_o$

and Change in temperature $\Delta T = T - T_o$

Like linear expansion, the change in volume ΔV is found to be proportional to its original volume V_o and change in temperature ΔT. Thus

$$\Delta V \propto V_o \Delta T$$

or $$\Delta V = \beta V_o \Delta T \quad \text{.........} \quad \text{(i)}$$

or $$V - V_o = \beta V_o \Delta T$$

or $$V = V_o + \beta V_o \Delta T$$

or $$V = V_o(1 + \beta \Delta T) \quad \text{.........} \quad \text{(ii)}$$

where β is the temperature coefficient of volume expansion. Using equation (i), we get

$$\beta = \frac{\Delta V}{V_o \Delta T} \quad \text{(iii)}$$

Coefficient of volume expansion β:

Thus, we can define the temperature coefficient of volume expansion β as the fractional change in its volume per kelvin change in temperature. The coefficients of linear expansion and volume expansion are related by the equation:

$$\beta = 3\alpha \quad \text{...............} \quad \text{(iv)}$$

8.8 Define specific heat. How would you find the specific heat of a solid?

Ans: Specific heat:

Specific heat of a substance is the amount of heat required to raise the temperature of 1 kg mass of that substance through 1K.

It has been observed that the quantity of heat ΔQ required to raise the temperature ΔT of a body is proportional to the mass m of the body. Thus

$$\Delta Q \propto m \Delta T$$

or $$\Delta Q = c m \Delta T \quad \text{...............} \quad \text{(i)}$$

Here ΔQ is the amount of heat absorbed by the body and c is the constant of proportionality called the specific heat capacity or simply specific heat.

Mathematically,

$$c = \frac{\Delta Q}{m \Delta T} \quad \text{(ii)}$$

Unit of specific heat:

SI unit of specific heat is $Jkg^{-1}K^{-1}$.

8.9 Define and explain latent heat of fusion.

Ans: Latent heat of fusion:

Heat energy required to change unit mass of a substance from solid to liquid state at its melting point without change in its temperature is called its latent heat of fusion.

It is denoted by H_f.

$$H_f = \frac{\Delta Q_f}{m}$$

or $$\Delta Q_f = m H_f \quad \ldots\ldots\ldots\ldots \quad (i)$$

Ice changes at 0°C into water. Latent heat of fusion of ice is $3.36 \times 10^5\ \mathrm{Jkg^{-1}}$ That is; 3.36×10^5 joule heat is required to melt 1 kg of ice into water at 0°C.

8.10 Define latent heat of vaporization.

Ans: Latent heat of vaporization:

The quantity of heat that changes unit mass of a liquid completely into gas at its boiling point without any change in its temperature is called its latent heat of vaporization.

It is denoted by H_v.

$$H_v = \frac{\Delta Q_v}{m}$$

or $$\Delta Q_v = m H_v \quad \ldots\ldots\ldots\ldots \quad (i)$$

When water is heated, it boils at 100°C under standard pressure. Its temperature remains 100°C until it is changed completely into steam. Its latent heat of vaporization is $2.26 \times 10^6\ \mathrm{Jkg^{-1}}$. That is; one kilogramme of water requires 2.26×10^6 joule heat to change it completely into gas (steam) at its boiling point.

8.11 What is meant by evaporation? On what factors the evaporation of liquid depends? Explain how cooling is produced by evaporation.

Ans: The evaporation:

Evaporation is the changing of a liquid into vapours (gaseous state) from the surface of the liquid without heating it.

Evaporation causes cooling:

Evaporation plays an important role in our daily life. Wet clothes dry up rapidly when spread. During evaporation; fast moving molecules escape out from the surface of the liquid. Molecules that have lower kinetic energies-l are left behind. This lowers the average kinetic energy of the liquid molecules and the temperature of the liquid. Since temperature of a substance depends on the average kinetic energy of its molecules. Evaporation of perspiration helps to cool our bodies.

- $T \propto K.E$

Evaporation takes place at all temperature from the surface of a liquid. The rate of evaporation is affected by various factors.

Factors affecting the rate of evaporation:

i. Temperature:

Why wet clothes dry up more quickly in summer than in winter? At higher temperature, more molecules of a liquid are moving with high velocities. Thus, more molecules escape from its surface. Thus, evaporation is faster at high temperature than at low temperature.

ii. Surface area:

Why water evaporates faster when spread over large area? Larger is the surface area of a liquid, greater number of molecules has the chance to escape from its surface.

iii. Wind:

Wind blowing over the surface of a liquid sweeps away the liquid molecules that have just escaped out. This increases the chance for more liquid molecules to escape out.

iv. Nature of the liquid:

Does spirit and water evaporate at the same rate? Liquids differ in the rate at which they evaporate. Spread a few drops of ether or spirit on your palm. You feel cold, why?

PROBLEMS

8.1 Temperature of water in a beaker is 50°C. What is its value in Fahrenheit scale? (122 °F)

Solution: Temperature in Celsius scale = C = 50°C

Temperature in Fahrenheit scale = F = ?

$$F = 1.8C + 32$$

$$F = 1.8 \times 50 + 32 = 90 + 32$$

$$F = 122°F$$

8.2 Normal human body temperature is 98.6°F. Convert it into Celsius scale and Kelvin scale. (37 °C, 310 K)

Solution: Temperature in Fahrenheit scale = 98.6°F

(i) Temperature in Celsius scale = ?

(ii) Temperature in Kelvin scale = ?

(i)

$$F = 1.8C + 32$$

$$1.8C = F - 32$$

$$1.8C = 98.6 - 32$$

$$1.8C = 66.6$$

$$C = \frac{66.6}{1.8} = 37°C$$

(ii)

$$T(K) = C + 273$$

$$T(K) = 37 + 273$$

$$T(K) = 310K$$

8.3 Calculate the increase in the length of an aluminum bar 2 m long when heated from 0°C to 20 °C. If the thermal coefficient of linear expansion of aluminum is 2.5×10^{-5} K^{-1}. (0.1 cm)

Solution: Original length of rod = L_o = 2 m

Initial temperature = T_o = 0 °C = 0 + 273 = 273 K

Final temperature = T = 20 °C = 20 + 273 = 293 K

Change in temperature = $\Delta T = T - T_o$ = 293 – 273 = 20 K

Coefficient of linear expansion of aluminum = $\alpha = 2.5 \times 10^{-5}$ K^{-1}

Increase in volume ΔL = ?

$\Delta L = \propto L_o \Delta T$
$\Delta L = 2.5 \times 10^{-5} \times 2 \times 20$
$\Delta L = 100 \times 10^{-5}$
$\Delta L = 0.001 \text{ m} = 0.001 \times 100 = 0.1 \text{ cm}$

8.4 A balloon contains 1.2 m^3 air at 15 °C. Find its volume at 40 °C. Thermal coefficient of volume expansion of air is 3.67×10^{-3} K^{-1}. (1.3 m^3)

Solution: Original volume = V_o = 1.2 m^3
Initial temperature = T_o = 15 °C = 15 + 273 = 288 K
Final temperature = T = 40 °C = 40 + 273 = 313 K
Change in temperature = $\Delta T = T - T_o$ = 313 - 288 = 25K
Coefficient of volume expansion of air $\beta = 3.67 \times 10^{-3}$ K^{-1}
Volume = V = ?
$V = V_o(1 + \beta \Delta T)$
$V = 1.2(1 + 3.67 \times 10^{-3} \times 25) = 1.2(1 + 91.75 \times 10^{-3})$
$= 1.2(1 + 0.09175) = 1.2 \times 1.09175$
$V = 1.3 \text{ m}^3$

8.5 . How much heat is required to increase the temperature of 0.5 kg of water from 10 °C to 65 °C? (115500 J)

Solution: Mass of water = m = 0.5 kg
Initial temperature = T_1 = 10°C = 10 + 273 = 283 K
Final temperature = T_2 = 65°C = 65 + 273 = 338 K
Change in temperature = $\Delta T = T_2 - T_1$ = 338- 283 = 55K
Heat = ΔQ = ?
$\Delta Q = mc\Delta T$
$\Delta Q = 0.5 \times 2400 \times 55$
$\Delta Q = 115500$ J

8.6 An electric heater supplies heat at the rate of 1000 joule per second. How much time is required to raise the temperature of 200 g of water from 20 °C to 90 °C? (58.8 s)

Solution: Power = P = 1000 Js^{-1}
Mass of water = m = 200 g = $\frac{200}{1000}$ = 0.2 kg
Initial temperature = T_2 = 20 °C = 20 + 273 = 293 K
Final temperature = T_1 = 90 °C = 90 + 273 = 363 K
Change in temperature = $\Delta T = T_2 - T_1$ = 363 - 293 = 70K
Specific heat of water = c = 4200 Jkg^{-1}K^{-1}
Time = t = ?
$P = \frac{W}{t}$
or $P = \frac{Q}{t}$
or $P \times t = Q$
or $P \times t = mc\Delta T$
or $t = \frac{mc\Delta T}{P}$
$t = \frac{0.2 \times 4200 \times 70}{1000} = 58.8 \text{ s}$

8.7 How much ice will melt by 50000 J of heat? Latent heat of fusion of ice = 336000 J kg^{-1}. (149 g)

Solution: Amount of heat required to melt ice = ΔQ_f = 50000 J

Latent heat of fusion of ice = H_f = 336000 Jkg^{-1}

Amount of ice = m = ?

$$\Delta Q_f = mH_f$$

or
$$m = \frac{\Delta Q_f}{H_f}$$

$$m = \frac{50000}{336000} = 0.1488 \text{ kg}$$

$$= 0.1488 \times 1000 = \frac{1488}{10000} \times 1000 = 148.8 \text{ g} \approx 149 \text{ g}$$

8.8 Find the quantity of heat needed to melt 100g of ice at -10 °C into water at 10°C. (39900 J)

(Note: Specific heat of ice is 2100 Jkg^{-1}K^{-1}, specific heat of water is 4200 Jkg^{-1}K^{-1}, Latent heat of fusion of ice is 336000 Jkg^{-1}).

Solution: Mass of ice = m = 100 g = $\frac{100}{1000}$ = 0.1 kg

Specific heat of ice = c1 = 2100 Jkg^{-1} K^{-1}

Latent heat of fusion of ice = L = 336000 Jkg^{-1}

Specific heat of water = c = 4200 Jkg^{-1} K^{-1}

Quantity of heat required = Q = ?

Case I:

Heat gained by ice from -10°C to 0°C

$$Q_1 = mc\Delta T$$

$$Q_1 = 0.1 \times 2100 \times 10 = 2100 \text{ J}$$

Case II:

Heat required for ice to melt $= Q_2 = mL$

$$= 0.1 \times 336000$$

$$Q_2 = 33600\text{J}$$

Case III:

Heat required to raise the temperature of water from 0°C to 10°C

$Q_3 = mc\Delta T$

$Q_3 = 0.1 \times 4200 \times 10 = 4200$ J

Total heat required = $Q = Q_1 + Q_2 + Q_3$

$$Q = 2100 + 33600 + 4200$$

$$Q = 39900 \text{ J}$$

8.9 How much heat is required to change 100 g of water at 100 °C into steam? (Latent heat of vaporization of water is 2.26 × 10^6 Jkg^{-1}. (2.26 × 10^5 J)

Solution: Mass of water = m = 100 g = $\frac{100}{1000}$ = 0.1 kg

Latent heat of vaporization of water = H_v = 2.26 × 10^6 Jkg^{-1}

Heat required = ΔQ_v = ?

$$\Delta Q_v = mH_v$$

$$\Delta Q_v = 0.1 \times 2.26 \times 10^6 = 0.226 \times 10^6 = \frac{226}{1000} \times 10^6$$

$$= 2.26 \times 10^{-1} \times 10^6 = 2.26 \times 10^5 \text{ J}$$

8.10 Find the temperature of water after passing 5 g of steam at 100 °C through 500 g of water at 10 °C. (16.2°C)
(Note: Specific heat of water is 4200 $Jkg^{-1}K^{-1}$, Latent heat of vaporization of water is 2.26×10^6 Jkg^{-1}).

Solution: Mass of stream = m_1 = 5 g = $\frac{5}{1000}$ kg = 0.005 kg

Temperature of stream = T_1 = 100 °C

Mass of water = m_2 = 0.5 kg

Temperature of water = T_2 = 10 °C

Final temperature = T_3 = ?

Case I:

Latent heat lost by stream = $Q_1 = mL$

$Q_1 = 0.005 \times 2.26 \times 10^6 = 11.3 \times 10^3 = 11300$ J

Case II:

Heat lost by stream to attain final temperature $Q_2 = m_1 c\, \Delta T$

$$Q_2 = 0.005 \times 4200 \times (100 - T_3)$$
$$Q_2 = 21\,(100 - T_3)$$

Case III:

Heat gained by water $Q_3 = m_2 c\, \Delta T$

$$Q_3 = 0.5 \times 4200 \times (T_3 - 10)$$
$$Q_3 = 2100\,(T_3 - 10)$$

According to the law of heat exchange.

Heat lost by stream = Heat gained by water

$$Q_1 + Q_2 = Q_3$$
$$11300 + 21\,(100 - T_3) = 2100\,(T_3 - 10)$$
$$11300 + 2100 - 21\,T_3 = 2100\,T_3 - 21000$$
$$13400 + 21000 - 21\,T_3 = 2100\,T_3 + 21\,T_3$$
$$34400 = 2121\,T_3$$
$$T_3 = \frac{34400}{2121}$$
$$T_3 = 16.2\ °C$$